VOLTAGE CONTROLLED OSCILLATOR (VCO) USING BIPOLAR JUNCTION TRANSISTOR

Project Work Submitted to

Vidyasagar University

Required for Partial Fulfilment of Degree

Master of Science in Physics

BY

Sumit Bhattacharjee

(ROLL-0012PHS15 NO-00015, REGN NO: D\0011PHS1500015 OF: 2015-16)

Malabika Maity

(ROLL-0012PHS15 NO-00048, REGN NO: D\0011PHS1500048 OF: 2015-16)

Kamalesh Chakraborty

(ROLL-0012PHS15 NO-00010, REGN NO: D\0011PHS1500010 OF: 2015-16)

Nayantara Majee

(ROLL-0012PHS14 NO-00009, REGN NO: D\0011PHS1400009 OF: 2014-15)

Under the guidance of

Dr. Radha Raman Pal

Department of Physics and Techno Physics
Vidyasagar University
Midnapore , West Bengal, Pin-721102

Introduction:

A key circuit used in modern communication devices is the ***Voltage Controlled Oscillator*** (***VCO***). A **voltage-controlled oscillator** (**VCO**) is an electronic oscillator whose oscillation frequency is controlled by a voltage input. The applied input voltage determines the instantaneous oscillation frequency. Consequently, a VCO can be used for frequency modulation (FM) or phase modulation (PM) by applying a modulating signal to the control input. A VCO is also an integral part of a phase-locked loop.

In today's wireless communication systems, a greater maximum frequency range is required by VCOs. With respect to the digital phones that use these circuits low power consumption, small size and low fabrication costs are important design factors.

Figure 1: A microwave (12-18GHz) Voltage Controlled Oscillator

Types of VCO:

VCOs can be generally categorized into two groups based on the type of waveform produced.

- *Linear* or *harmonic oscillators* generate a sinusoidal waveform. Harmonic oscillators in electronics usually consist of a resonator with an amplifier that replaces the resonator losses (to prevent the amplitude from decaying) and isolates the resonator from the output (so the load does not affect the resonator). Some examples of harmonic oscillators are LC oscillators and crystal oscillators. In a voltage-controlled oscillator, a voltage input controls the resonant frequency. A varactor diode's capacitance is controlled by the voltage across the diode. Varactor is used to change the capacitance (and hence the frequency) of an LC tank. A varactor can also change loading on a crystal resonator and pull its resonant frequency.

- *Relaxation oscillators* can generate a saw tooth or triangular waveform. They are commonly used in integrated circuits (ICs). They can provide a wide range of operational frequencies with a minimal number of external components.

The Basic VCO Circuit:

A wide variety of circuit designs can be made to implement a voltage controlled oscillator using different voltage control electronic components like transistors, varactor diodes, OPAMPs, etc. The figure below shows a simple voltage control oscillator using astable multivibrator.

In this a time constant resistors R1 and R2 brought out to an external control line $V_{control}$. The voltage to which C1 and C2 discharges through R1 and R2 changes with change in $V_{control}$ voltage. Hence the discharging speed is increases with increase of $V_{control}$.

This arrangement changes the base voltage to which the base of the transistor must climb or descend. Therefore, by these RC elements and turn ON or OFF of the transistors alter the operating frequency of oscillations at the output.

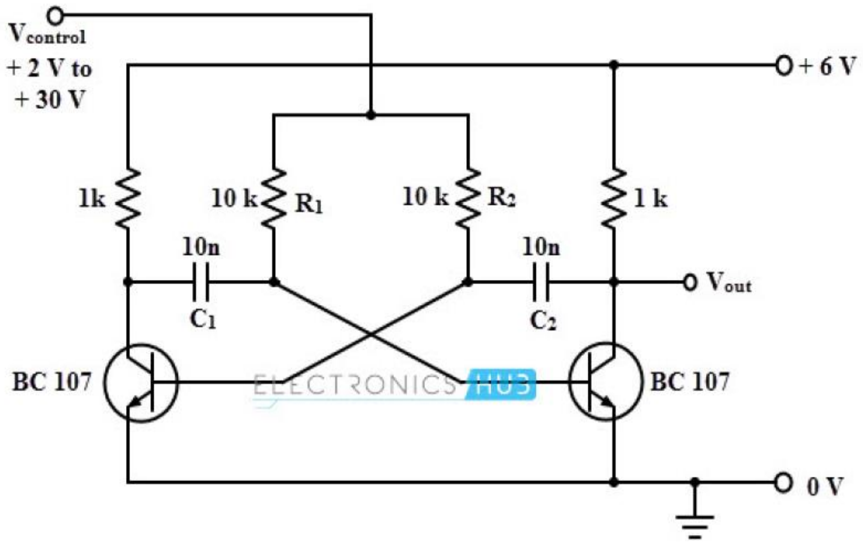


Figure 2: The basic VCO Circuit

In our preparatory experiment we have used the transistor Q2N3904 in place of the transistor BC107, thus resulting the circuit given in the **Figure 3**. The voltage output of the circuit is shown in the **Figure 4**.

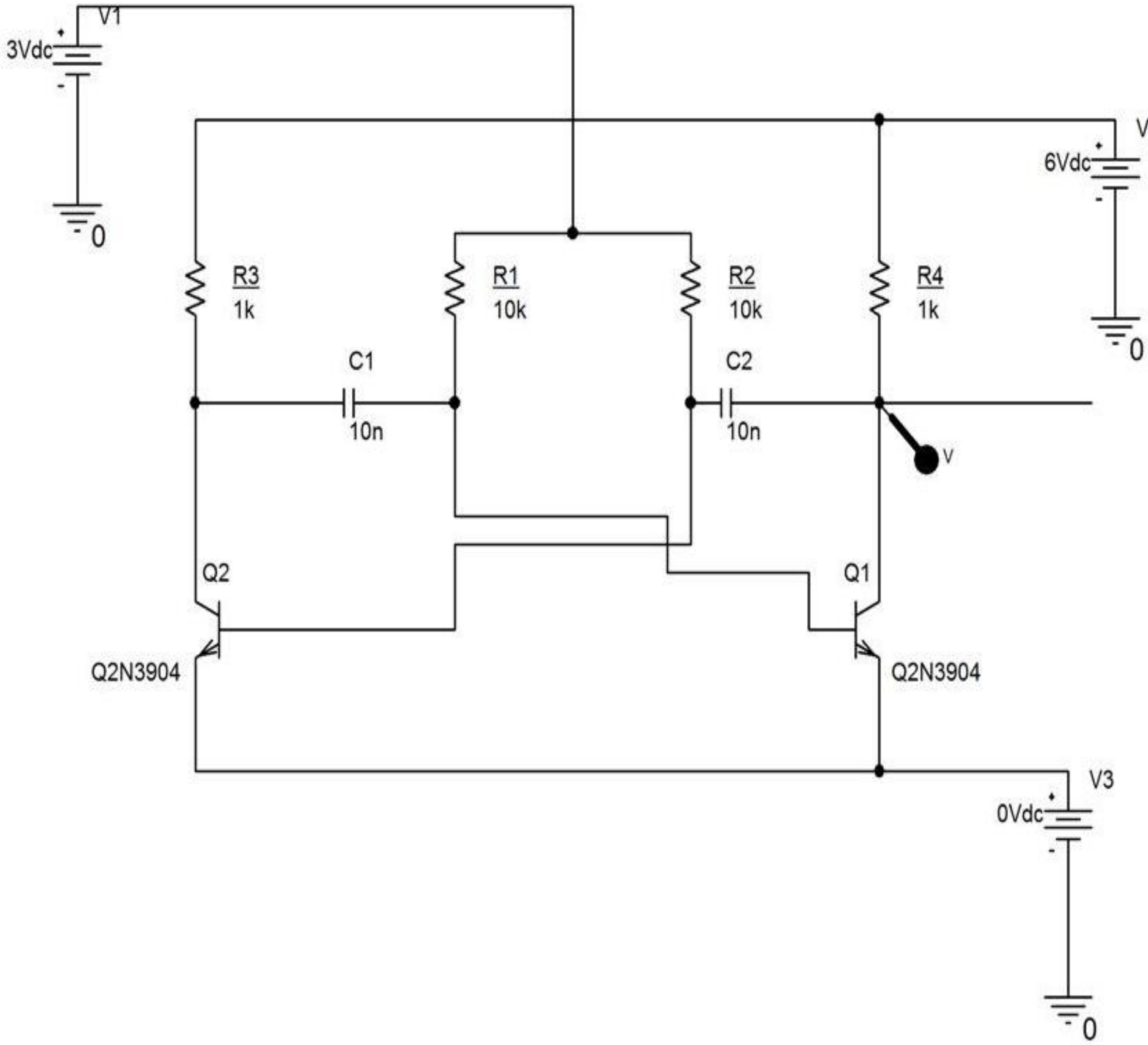


Figure 3: The basic VCO Circuit used in our experiment

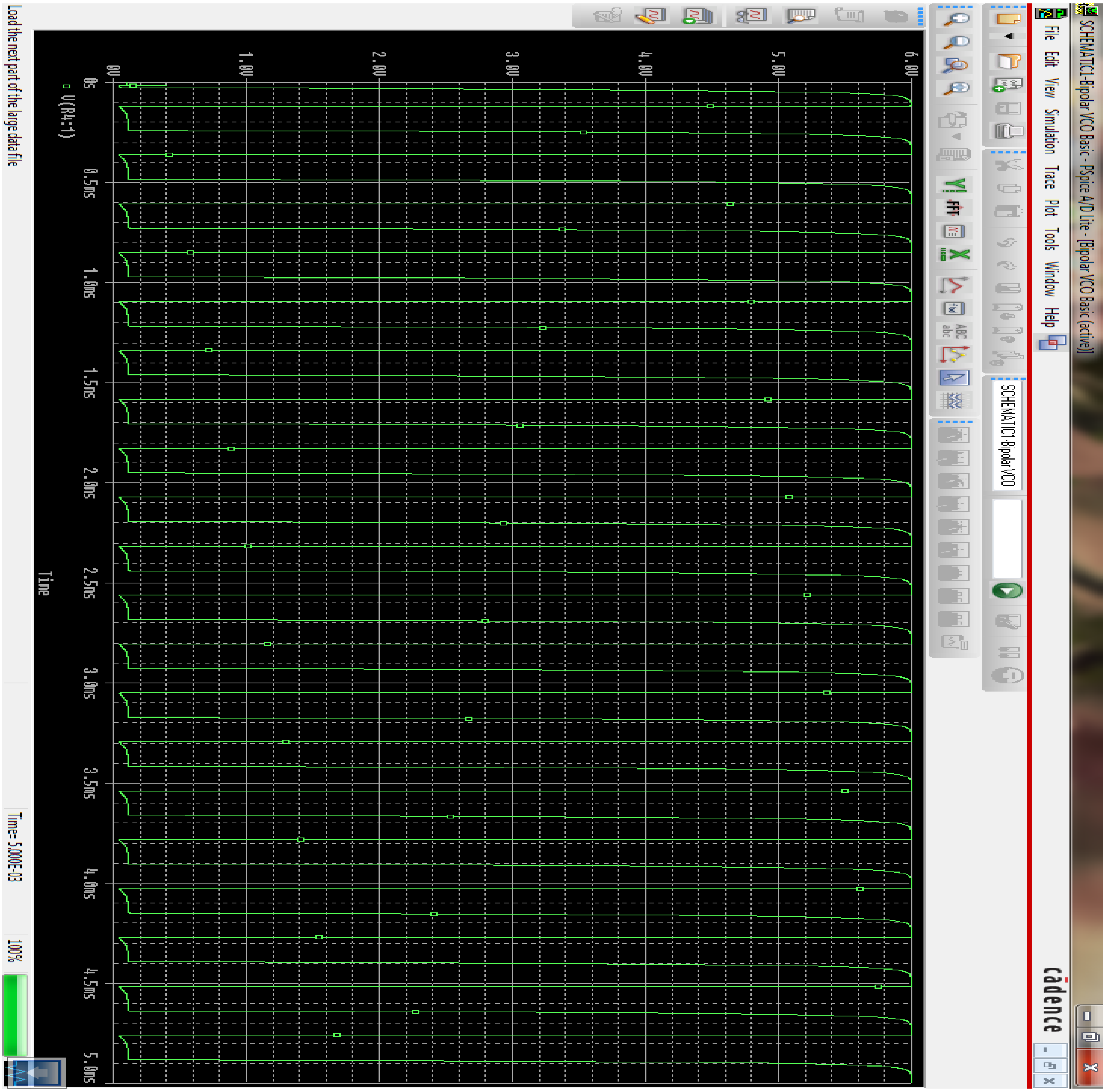
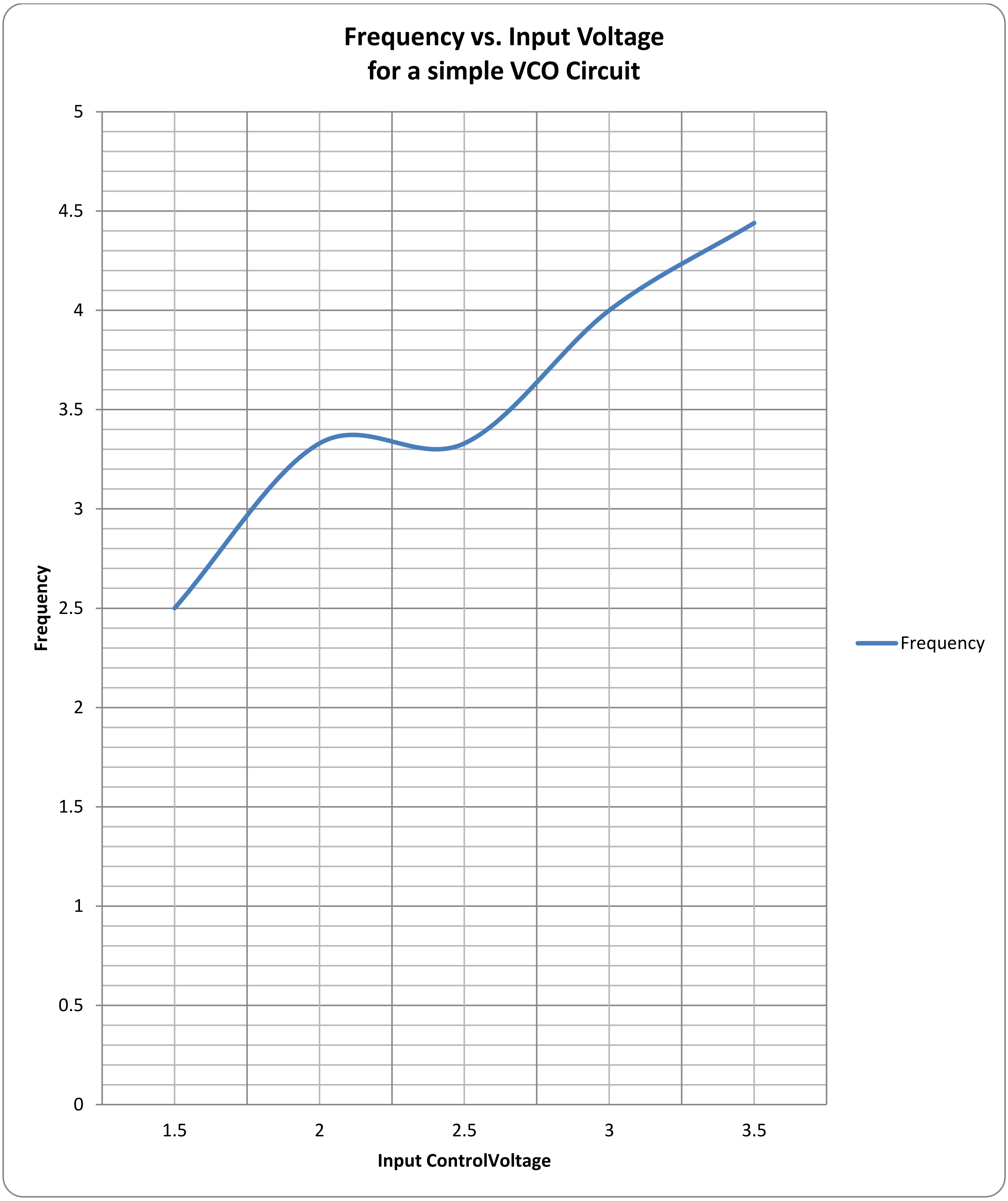


Figure 4: The Voltage Output of a Basic Bipolar VCO

If we plot the frequency of the variation of the output voltage (along y-axis) as a function of the input control voltage (along x-axis), then we obtain a graph as shown in **Graph I**.

Table 1

Voltage (V)	**Frequency (kHz)**
1.5	2.5
2	3.33
2.5	3.33
3	4
3.5	4.44



Graph I: Frequency vs. Input Control Voltage

Experiment:

Theory:

A RC relaxation oscillator consists of two cross coupled transistors with their emitters connected to the ends of a capacitor. **Figure 5** shows a bipolar version of the oscillator. Q3 and Q4 are emitter follower buffers. The emitters of Q1 and Q2 are connected to voltage controlled current sources (normally identical bipolar transistors Q7 and Q8). When Q1 is on, its collector voltage holds Q2 off and the emitter current of Q1 charges the capacitor. When the emitter voltage of Q1 rises above two V_{be} drops from V_{CC} Q1 turns off, Q2 turns on and the emitter current of Q2 charges the capacitor. The amount of current that flows into the capacitor depends upon the voltage controlled current source (the collector currents of Q7 and Q8). The frequency at which the capacitor voltage oscillates is given by:

$$F_{osc} = I(V_{in})/(4*V_{be}*C)$$

Where, $I(V_{in})$ is the current from the voltage controlled current source. V_{be} is known as a swing voltage (the maximum voltage across C before the transistors switch).

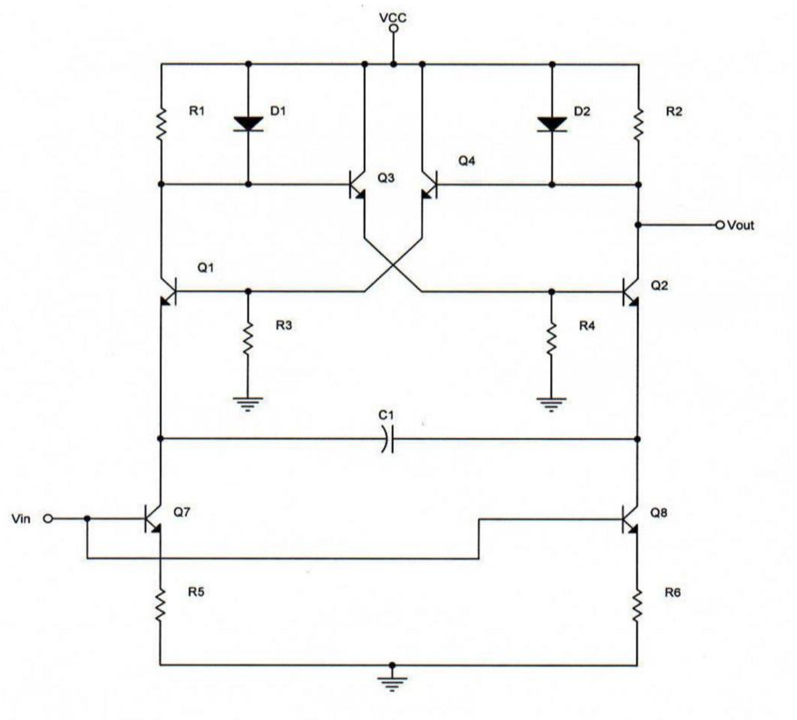


Figure 5: An emitter coupled relaxation voltage controlled oscillator

The active components of the simplest relaxation oscillators consist of four transistors.

The transistors can either be emitter-coupled or collector-coupled. Emitter coupled circuit exhibit sudden voltage jumps at both ends of the capacitor. The voltage jumps create excessive current spikes and possible substrate injection. Sudden voltage jumps do not occur in collector-coupled circuits. Variations of the circuit have used Schmitt triggers or SR latches to drive the capacitor.

Components:

1. Q2N2222 Transistor:

The **2N2222** is a common NPN bipolar junction transistor (BJT) used for general purpose low-power amplifying or switching applications. It is designed for low to medium current, low power, medium voltage, and can operate at moderately high speeds. It was originally made in the TO-18 metal can as shown in the picture.

The 2N2222 is considered a very common transistor, and is used as an exemplar of an NPN transistor. It is frequently used as a small-signal transistor, and it remains a small general purpose transistor of enduring popularity.

The 2N2222 was part of a family of devices described by Motorola at a 1962 IRE convention. Since then it has been made by many semiconductor companies, for example, Texas Instruments

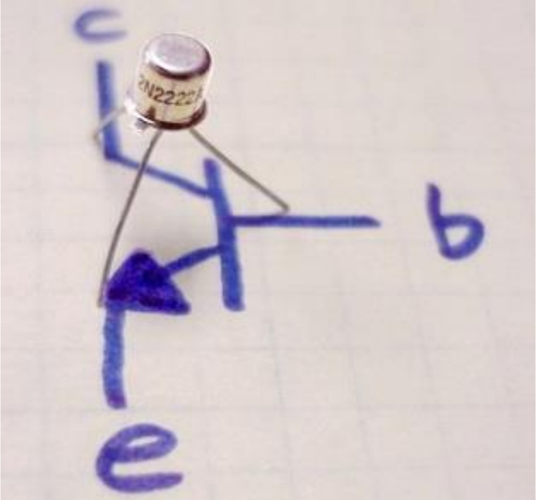


Figure 6: A 2N2222 Transistor

2. **D1N4148 Diode:**

The **1N4148** is one of the standard silicon switching signal diodes. It is one of the most popular and long-lived switching diodes because of its dependable specifications and low cost. Its name follows the JEDEC nomenclature. The 1N4148 is useful in switching applications up to about 100 MHz with a reverse-recovery time of no more than 4 ns.

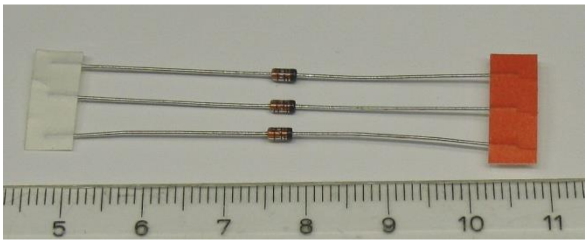


Figure 7: 1N4148 Diode

3. Resistors
4. Capacitors
5. Voltage Sources, and
6. Ground

Results:

We have used the transistor Q2N2222 as the BJT component of our VCO circuit. The resistances are all 1kΩ, the capacitor used is of 10nF. The source voltage is set to 9V. The control voltage is varied from 2V to 5V. The screenshot of the variation of the output voltage with respect to the input control voltage of 3V over a time of 100 microseconds is given in **Figure 9**.

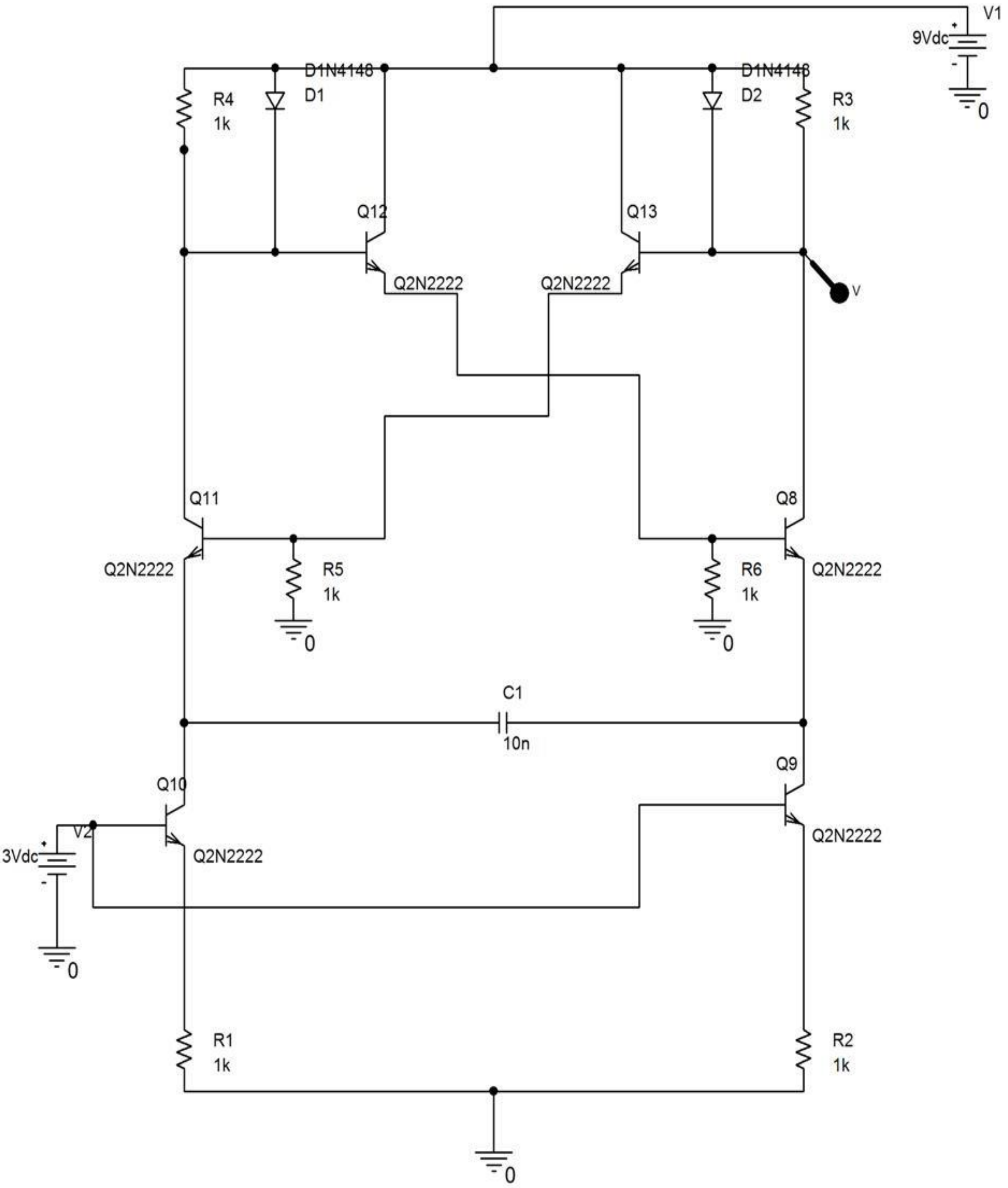
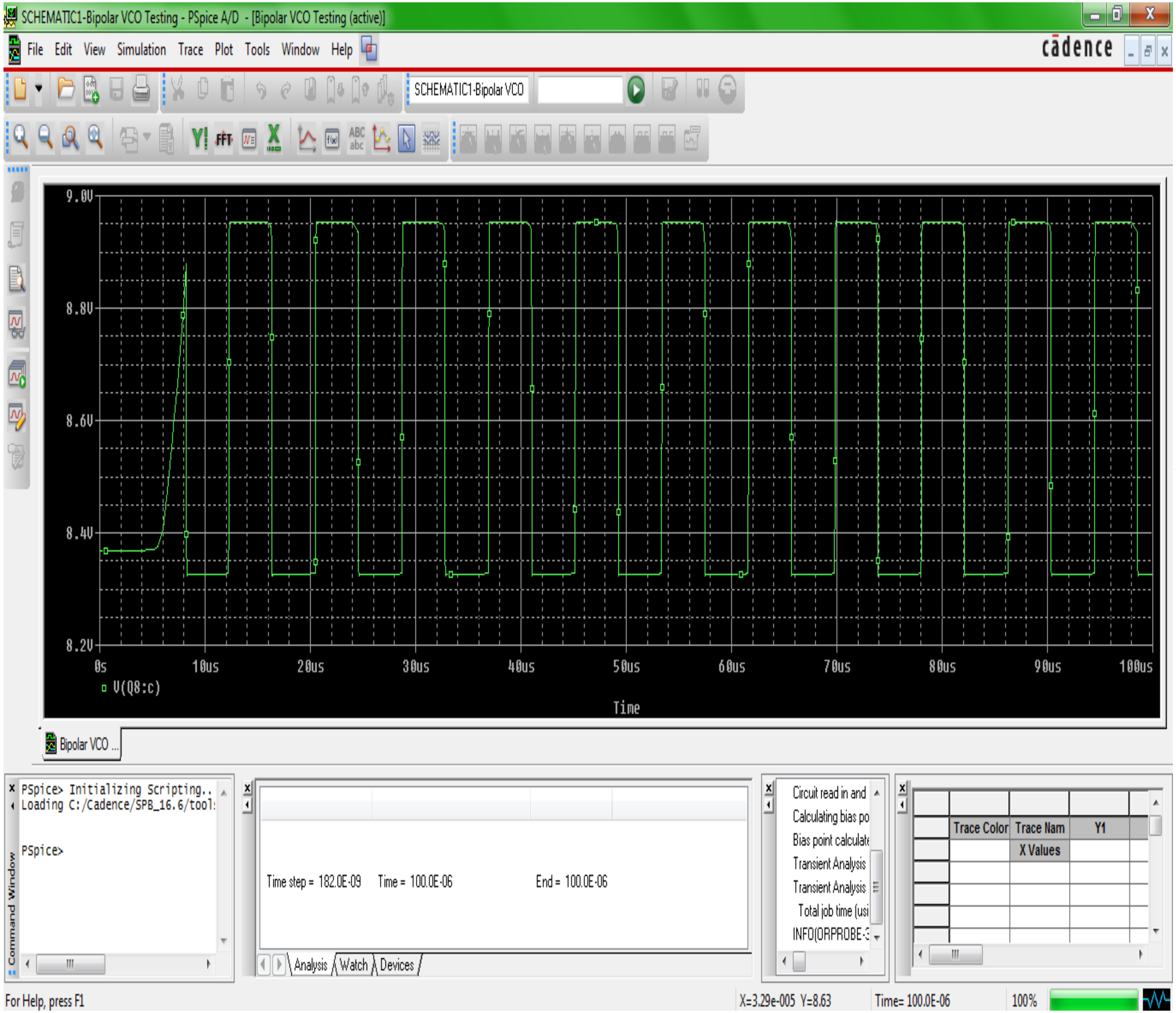


Figure 8: Experimental Circuit



```
PSpice> Initializing Scripting..
Loading C:/Cadence/SPB_16.6/tool:

PSpice>
```

Time step = 182.0E-09   Time = 100.0E-06   End = 100.0E-06

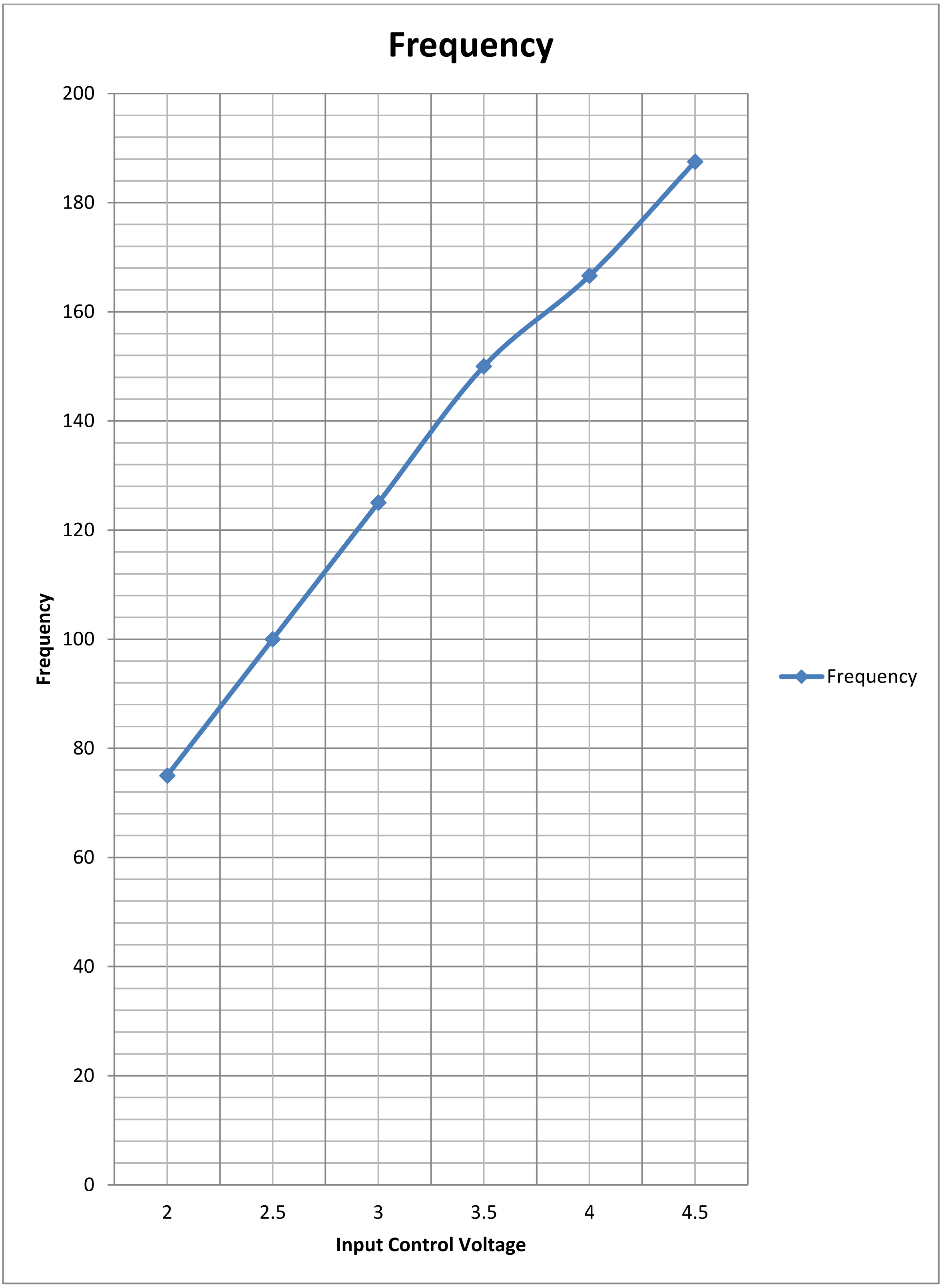
```
Circuit read in and
Calculating bias po
Bias point calculate
Transient Analysis
Transient Analysis
 Total job time (usi
INFO(ORPROBE-3
```

Figure 9: The Voltage Output of our Experimental Circuit
]

Again if we plot the variation of the frequency of the output voltage (along y-axis) as a function of the input control voltage (along x axis) (as we have done in the case of the former simple VCO circuit), we obtain a graph as shown in the **Graph II**.

Table 2

Voltage (V)	**Frequency (kHz)**
2	75
2.5	100
3	125
3.5	150
4	166.6
4.5	187.5
5	214.3



Graph II: Frequency vs. Input Control Voltage

Again, we have repeated the circuit replacing the transistor Q2N2222 by another transistor Q2N3904[1] (**Figure 11**), to test the output waveform pattern and the frequency stability of the given configuration. The output waveform we obtained follows the same pattern in spite of the change of the transistor. The variation of the output voltage with respect to the input control voltage is measured over a time of 100 microseconds just after switching ON the circuit, and given in the **Figure 12**.

---

[1] ***Note:***

The **2N3904** is a common NPN bipolar junction transistor used for general-purpose low-power amplifying or switching applications. The type was registered by Motorola Semiconductor in the mid-1960s, together with the complementary PNP type 2N3906, and represented a significant performance/cost improvement, with the plastic TO-92 case replacing metal cans. It is designed for low current and power, medium voltage, and can operate at moderately high speeds. This transistor is low-cost, widely available and sufficiently robust to be of use by experimenters and electronics hobbyists. When looking at the flat side with the leads pointed downward, the three wires emerging from the bottom are connected to, from left to right, the emitter, the base and the collector. Some manufacturers mark "EBC" on the moulded part, but all are required to have those connections for a part which is a "2N3904".

It is a 200 mA, 40 V, 625 mW transistor with a transition frequency of 300 MHz, with a minimal beta, or current gain, of 100 at a collector current of 10 mA. It is used in a variety of analog amplification and switching applications.

The 2N3904 is used very frequently in hobby electronics projects, including home-made ham radios, code-practice oscillators and as an interfacing device for microcontrollers.

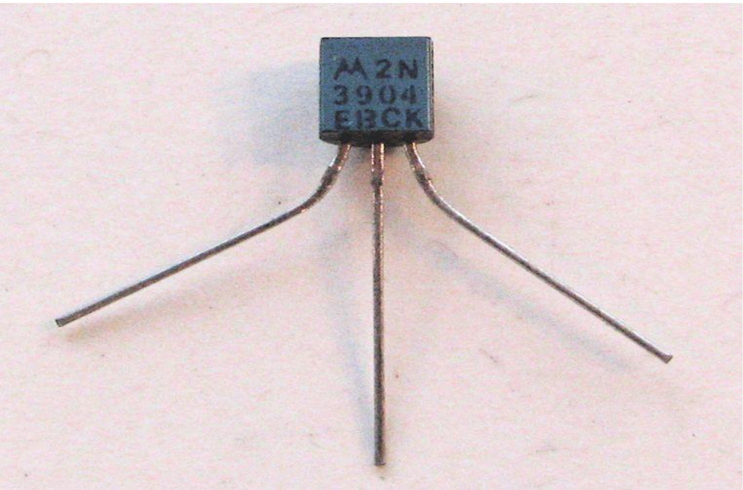


Figure 10: A 2N3904 made by Motorola. The pinout from left to right is: Emitter, Base and Collector.

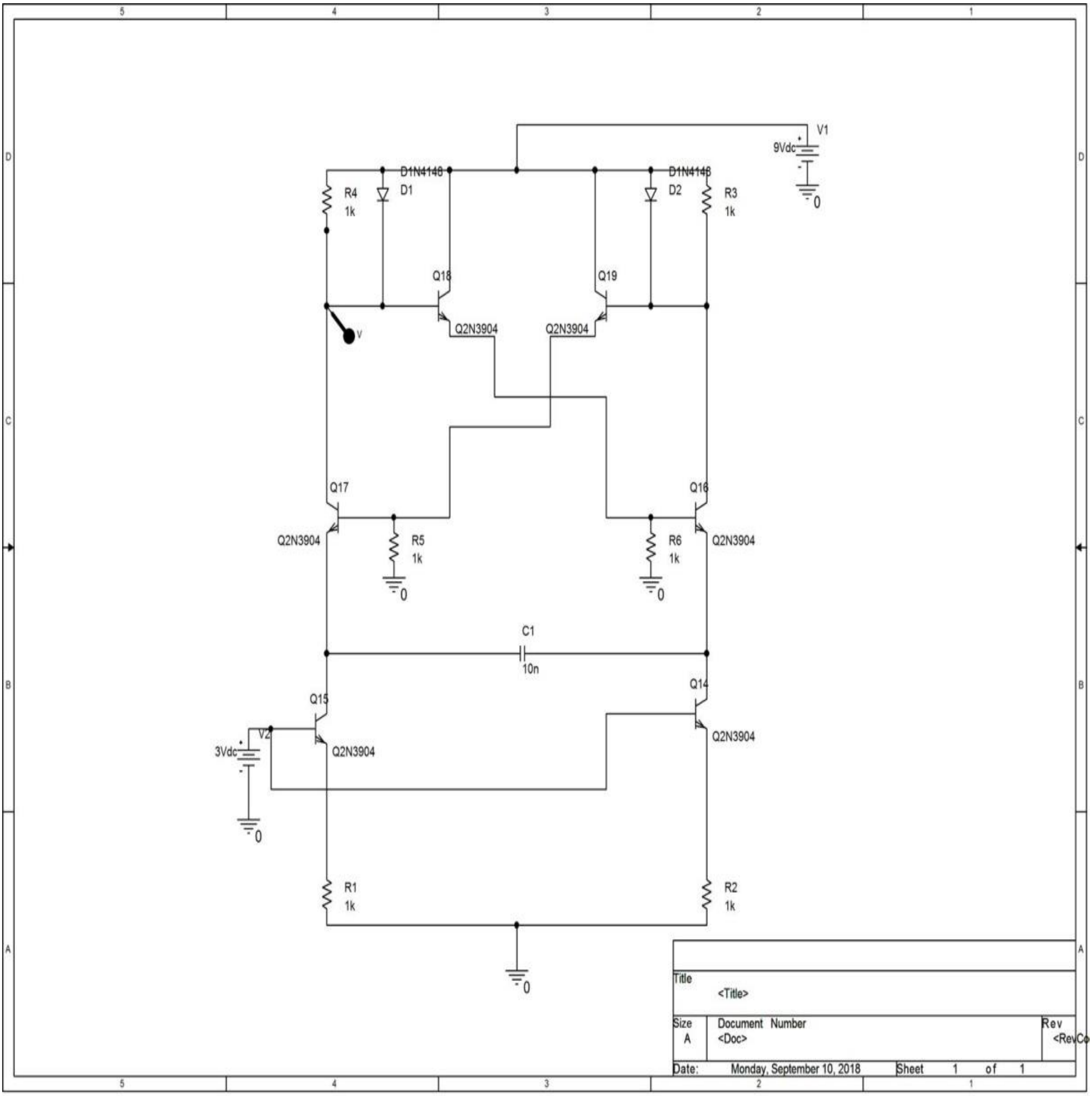
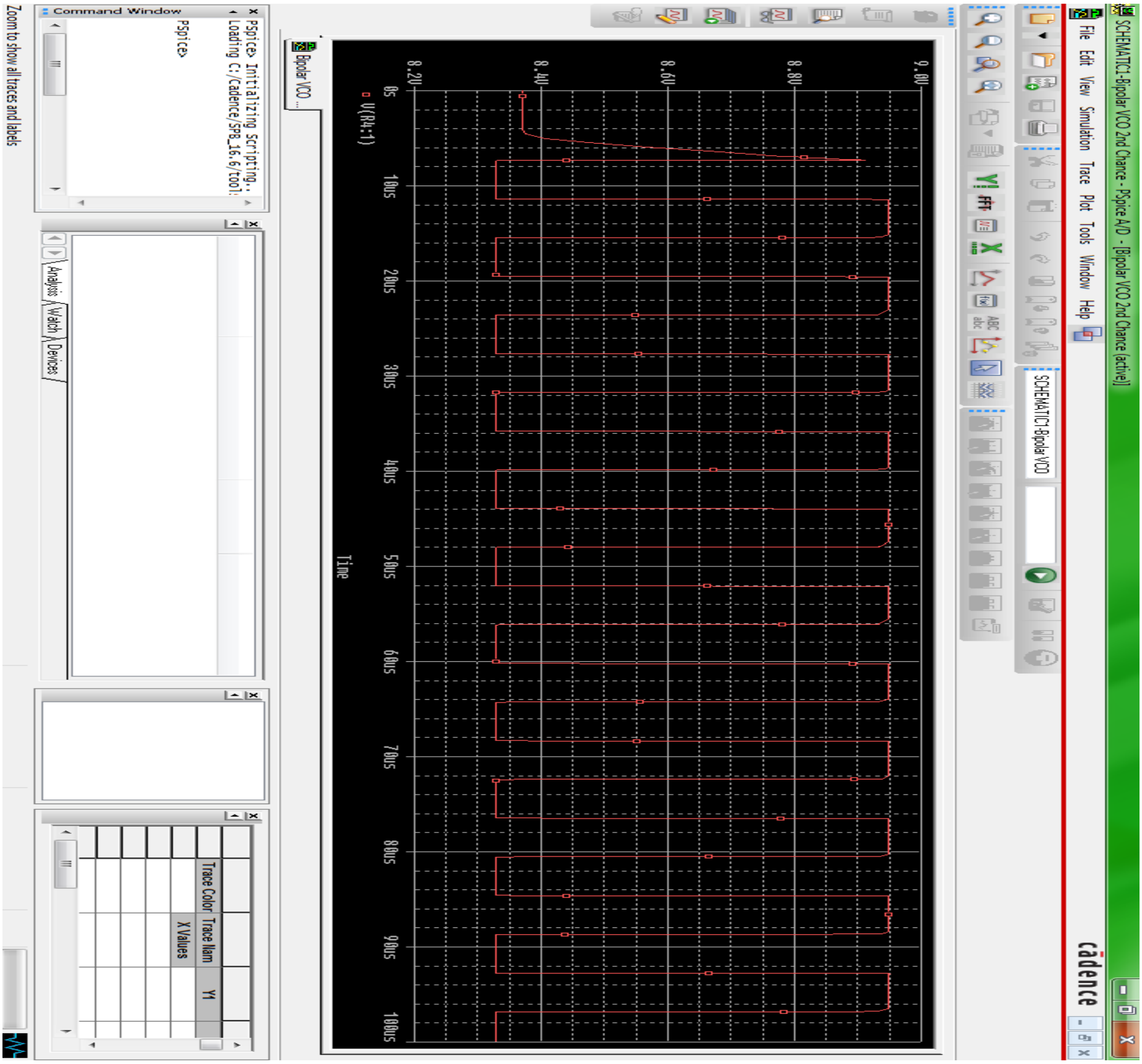


Figure 11: Another Experimental Circuit



```
PSpice> Initializing scripting...
Loading C:/Cadence/SPB_16.6/tool...
PSpice>
```

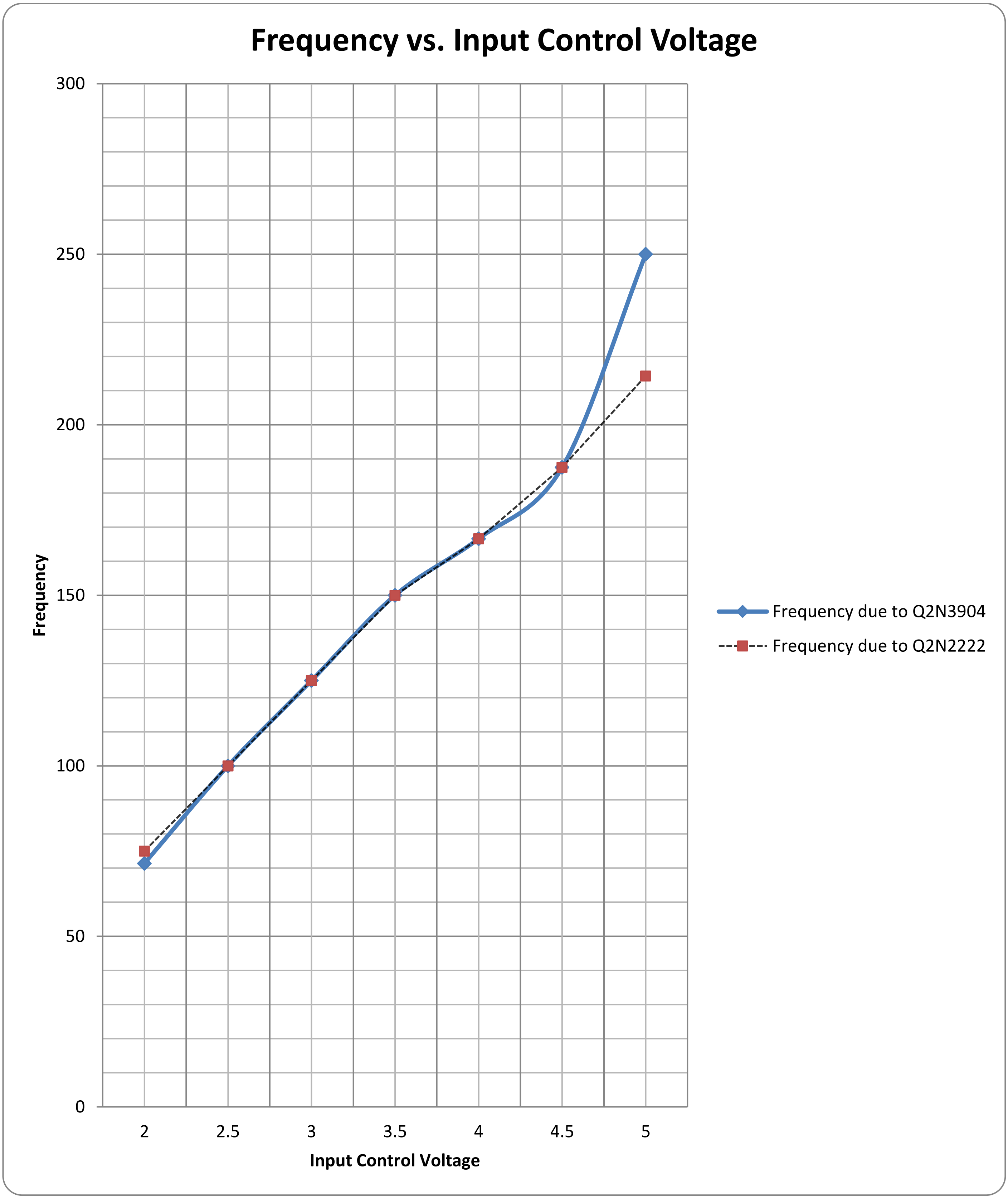
Zoom to show all traces and labels

Figure 12: The Voltage Output of the second Experimental Circuit

The plot of output voltage frequency (along y-axis) with respect to the input control voltage (along x-axis) is given in the next figure. The compare with the former configuration the previous graph is plotted with the dotted line.

Table 3

Voltage (V)	**Frequency (kHz)**
2	71.4
2.5	100
3	125
3.5	150
4	166.6
4.5	187.5
5	250



Graph III: Frequency vs. Input Control Voltage of the second Experimental Circuit

Discussions:

The benefits of relaxation oscillators include a large frequency tuning range, a low cost, a very linear frequency versus voltage relationship and a requirement of only a single reactive component. Also, all of the components of this oscillator can be fabricated on a single IC. However, these circuits have poor frequency stability at high frequencies and are more susceptibility to phase noise compared to LC oscillator. Also, the relaxation oscillator cannot generate a pure sine wave. If the output Is referenced at one of the collector nodes then the measured signal will be square wave(with peaks between V_{CC} and GROUND) where as the voltage across the capacitor will be a saw-tooth wave with its mean voltage at zero volts.

The output frequency of the relaxation oscillators is also dependent on the circuit temperature. V_{be} is inversely proportional to temperature. Therefore as temperature increases the oscillation frequency will increase when the input voltage remains constant.

The Future of VCOs:

As the communications industry evolves, especially in the wireless domain, there will be greater demand for faster data rates, smaller devices and lower power consumption. These demands will push the envelope of VCO design beyond today's limitations. The highest challenge for designers is to find an optional balance between these requirements.

Faster switching devices will be necessary to drive oscillators at higher frequencies. Enhanced phase noise reduction circuitry will be needed to ensure the stability of multi gigahertz signals without sacrificing low power requirements. As CMOS fabrication techniques continue to advance, relaxation oscillators (designed as ring oscillators) will be able to meet these demands with performance comparable to LC oscillators but with the benefit of being constructed on smaller surface areas.

For LC oscillators, improved fabrication techniques will allow high Q factor inductors to occupy less space on the integrated circuit and will allow the inductance value to be made more repeatable during the manufacturing process. An added benefit will be a wider range of inductor values that can be generated for use "on chip" thereby increasing the tuneable frequency range of the LC oscillator.

References:

1) Voltage Controlled Oscillators by Jeff Wilkin, University of Toronto, November 12, 2001
2) Voltage Controlled Oscillators (VCO), ELECTRONICS HUB, www.electronicshub.org
3) Voltage-controlled oscillator, WIKIPEDIA

Other Sources: WIKIPEDIA

Software Used: OrCAD CAPTURE CIS. Release 16.6